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INTEGRATED MAINTENANCE INFORMATION SYSTEM (IMIS) FINAL PROGRAM REPORT VOLUME 3: RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

Glenn Ward

GDE Systems, Inc.
16550 West Bernardo Drive
San Diego, CA 92150-9009

Tom M. Kruzick, Maj, USAF
Richard E. Weimer

HUMAN RESOURCES DIRECTORATE
LOGISTICS RESEARCH DIVISION
2698 G STREET
WRIGHT-PATTERSON AFB, OH 45433-7604

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Tom M Kruzick

TOM M. KRUZICK, Major, USAF
Contract Monitor

BERTRAM W. CREAM, GM-15, DAF
Chief, Logistics Research Division

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GDE Systems, Inc.
16550 West Bernardo Drive
San Diego, CA 92150-9009

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Volume three of the IMIS Final Report documents the results and conclusions of each field test or demonstration conducted at Luke Air Force Base. Recommendations and lessons learned collected during the entire program (e.g., requirements analysis, system design, implementation, integration, test, installation, and demonstration) are provided. The IMIS project was an advanced development demonstration project which developed and field tested the technology to provide the maintenance technician with the capability to access all of the technical information (interactive electronic technical manuals, interactive diagnostics instructions, work orders, supply availability and ordering, historical data, training material, etc.) required to maintain aircraft via a single, integrated system, regardless of the source of that information. In the final phase of the project, an IMIS Demonstration System was developed and tested. In the field test, the performance of technicians on troubleshooting tasks when using the IMIS was compared with their performance on comparable tasks when using the paper technical orders. Test results indicated that technicians were able to perform the tasks significantly faster, used fewer parts, and made fewer serious errors when using the IMIS. In addition, the test indicated that, when using IMIS, non-specialist (crew chief) technicians could perform the tasks as effectively as the specialists.

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PREFACE

This is the third volume of the IMIS Final Program Report. This volume documents the results and conclusions of each field test or demonstration conducted at Luke Air Force Base. Recommendations and lessons learned collected during the entire program (e.g., requirements analysis, system design, implementation, integration, test, installation, and demonstration) are provided. Finally, strategies for further implementation are included. The Debrief Test was composed of real maintenance debriefs and IMIS interaction with the production Core Automated Maintenance System (CAMS). Comparison of data collected revealed the average maintenance debrief time using IMIS was less than half the time required when using the current method. Although debriefs for discrepant aircraft kept the pilots involved for half a minute longer than the current method, total debrief time still averaged five minutes less when using IMIS. The End-to-End Demonstration exercised the primary functions of IMIS using a total of 32 expediters, production superintendents, maintenance debriefs, and technicians. Subjective data collected from the participants identified IMIS strengths as (1) ready availability of all needed technical order (TO) data, (2) insulation from keystroke-by-keystroke interaction with CAMS, and (3) part-ordering from the job site. The primary IMIS weakness was insufficient speed during certain transactions. The Fault Isolation Test successfully demonstrated the IMIS concept. Technicians were able to complete fault isolation and repair problems with greater accuracy, in a shorter time, and with fewer errors and fewer parts used in the process. The technicians had very little trouble using IMIS after a short training session. Both the specialist and airplane general (APG) technicians were able to perform the test tasks with minimal difficulty. In contrast, the APG technicians (and some specialists) experienced significant difficulties in using the paper TOs. The detailed results from the Fault Isolation Test are documented in separate Armstrong Laboratory reports (AL/HR-TP-1995-0033 and AL/HR-TP-1995-0034).

INTEGRATED MAINTENANCE INFORMATION SYSTEM (IMIS) RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

INTRODUCTION

This Final Program Report documents the results of each field test and demonstration conducted at Luke Air Force Base (AFB) as well as the conclusions that can be drawn from these results. In addition, recommendations and lessons learned collected during the entire program (e.g., requirements analysis, system design, implementation, integration, test, installation, and demonstration) are provided. Finally, recommendations and strategies for proceeding with further implementation are included.

RESULTS

The results of the Debrief Test, End-to-End Demonstration, and Fault Isolation Test are summarized in the following subsections.

Debrief Test

The Debrief Test was conducted at Luke AFB from November 3 through December 9, 1993. Data was collected by observing and timing actual debrief sessions, some using IMIS and the rest using the current method. Four maintenance debriefers participated to varying degrees over the six-week period; only two debriefers were involved in the majority of the debrief sessions. Information collected during the sessions included start and stop times, problems encountered, discrepancy data (for use in subsequent tracking of work orders), and observations or remarks.

The data for the Debrief Test was collected by observing live debrief sessions, therefore, the Debrief Test could not be designed to provide a statistically valid test of various hypotheses. Instead, a quantitative comparison of the data was performed to determine trends in the debrief data collected using IMIS and the current method. The data collected and the results are summarized in the following subsections.

IMIS Debrief Results

Forty-five debrief sessions using IMIS were observed. The data collected, including the amount of time the pilot was present, the total debrief time, and the number of work orders opened, is presented in Table 1.

Aircraft maintenance discrepancies were reported as they occurred from the scheduled aircraft sorties; discrepancies were reported in only 13 of the 45 IMIS debrief sessions. Such a small number of discrepancies was insufficient to support conclusions regarding the quantities of work orders opened and the effectiveness of the discrepancy information captured.

Table 1. IMIS Debrief Results

NUMBER	DATE	START TIME	PILOT DONE	END TIME	WORK ORDERS	CODE	PILOT TIME	DEBRIEF TIME
1	11/9/93	16:19	16:33	16:55	3	3	0:14	0:36
2	11/9/93	16:57	17:00	17:00	0	1	0:03	0:03
3	11/10/93	16:18	16:25	16:28	0	1	0:07	0:10
4	11/10/93	15:47	15:50	15:50	0	1	0:03	0:03
5	11/10/93	15:42	15:46	15:46	0	1	0:04	0:04
6	11/10/93	15:31	15:38	15:38	0	1	0:07	0:07
7	11/10/93	16:18	16:20	16:20	0	1	0:02	0:02
8	12/2/93	14:13	14:15	14:15	0	1	0:02	0:02
9	12/2/93	14:28	14:31	14:31	0	1	0:03	0:03
10	12/2/93	15:01	15:03	15:03	0	1	0:02	0:02
11	12/2/93	15:09	15:14	15:16	0	1	0:05	0:07
12	12/2/93	17:32	17:35	17:36	0	1	0:03	0:04
13	12/2/93	19:13	19:18	19:18	0	1	0:05	0:05
14	12/2/93	19:36	19:39	19:39	0	1	0:03	0:03
15	12/3/93	12:32	12:35	12:40	1	2	0:03	0:08
16	12/3/93	13:45	13:48	13:48	0	1	0:03	0:03
17	12/3/93	13:45	13:46	13:47	0	1	0:01	0:02
18	12/3/93	13:30	13:33	13:35	1	2	0:03	0:05
19	12/6/93	19:57	19:59	19:59	0	1	0:02	0:02
20	12/6/93	20:00	20:02	20:02	0	1	0:02	0:02
21	12/6/93	20:12	20:15	20:15	0	1	0:03	0:03
22	12/7/93	14:39	14:41	14:41	0	1	0:02	0:02
23	12/7/93	15:40	15:43	15:46	1	2	0:03	0:06
24	12/7/93	15:03	15:05	15:05	0	1	0:02	0:02
25	12/7/93	14:53	14:56	14:56	0	1	0:03	0:03
26	12/7/93	19:24	19:28	19:28	0	1	0:04	0:04
27	12/7/93	19:47	19:51	19:59	1	2	0:04	0:12
28	12/7/93	20:13	20:15	20:15	0	1	0:02	0:02
29	12/7/93	15:06	15:12	15:18	1	2	0:06	0:12
30	12/8/93	14:50	14:53	14:53	0	1	0:03	0:03
31	12/8/93	15:02	15:12	15:14	1	2	0:10	0:12
32	12/8/93	17:27	17:30	17:30	0	1	0:03	0:03
33	12/8/93	19:28	19:30	19:31	0	1	0:02	0:03
34	12/8/93	19:33	19:36	19:41	1	2	0:03	0:08
35	12/8/93	19:43	19:46	19:46	0	1	0:03	0:03
36	12/8/93	19:48	19:52	19:56	1	2	0:04	0:08
37	12/8/93	19:58	20:04	20:05	1	2	0:06	0:07
38	12/8/93	20:32	20:34	20:34	0	1	0:02	0:02
39	12/9/93	14:11	14:17	14:25	1	2	0:06	0:14
40	12/9/93	14:38	14:41	14:41	0	1	0:03	0:03
41	12/9/93	14:58	15:00	15:00	0	1	0:02	0:02
42	12/9/93	19:19	19:20	19:21	0	1	0:01	0:02
43	12/9/93	19:39	19:52	20:02	3	2	0:13	0:23
44	12/9/93	20:03	20:06	20:06	0	1	0:03	0:03
45	12/9/93	20:11	20:19	20:23	1	2	0:08	0:12

Minor problems were identified during the IMIS debrief sessions. These included discrepancies in the authored Fault Reporting Manual (FRM) data, recommended software enhancements (especially involving facilitating error correction), and environmental difficulties resulting when inundated with pilots to be debriefed. None of these problems significantly affected the outcome of the debrief sessions.

Paper Debrief Results

One hundred and eleven debrief sessions using the current paper-based system were observed. Data from two of these sessions was incomplete or inconsistent and was discarded, leaving a total of 109 data points. The data collected can be found in Table 2.

Table 2. Paper Debrief Results

NUMBER	DATE	START TIME	PILOT DONE	END TIME	WORK ORDERS	CODE	PILOT TIME	DEBRIEF TIME
101	11/3/93	18:57	19:06	19:13	2	3	0:09	0:16
102	11/3/93	18:59	19:02	19:08	1	2	0:03	0:09
103	11/3/93	19:11	19:15	19:18	0	1	0:04	0:07
104	11/3/93	19:11	19:15	19:20	1	2	0:04	0:09
105	11/3/93	19:49	19:51	20:08	4	2	0:02	0:19
106	11/3/93	19:52	19:59	20:11	0	1	0:07	0:19
107	11/3/93	19:57	20:01	20:18	2	2	0:04	0:21
108	11/3/93	20:23	20:28	20:35	2	2	0:05	0:12
109	11/3/93	20:14	20:16	20:20	0	1	0:02	0:06
110	11/4/93	14:05	14:11	14:17	1	2	0:06	0:12
111	11/4/93	14:33	14:35	14:36	0	1	0:02	0:03
112	11/4/93	14:33	14:37	14:40	0	1	0:04	0:07
113	11/4/93	15:04	15:09	15:09	0	1	0:05	0:05
114	11/4/93	15:09	15:13	15:33	1	2	0:04	0:24
115	11/4/93	15:09	15:15	15:20	0	1	0:06	0:11
116	11/4/93	15:09	15:16	15:25	3	3	0:07	0:16
117	11/4/93	15:14	15:17	15:23	0	1	0:03	0:09
118	11/4/93	15:14	15:18	15:28	0	1	0:04	0:14
119	11/4/93	15:24	15:27	15:33	0	1	0:03	0:09
120	11/4/93	15:25	15:26	15:33	0	1	0:01	0:08
121	11/4/93	19:02	19:05	19:06	0	1	0:03	0:04
122	11/4/93	19:02	19:07	19:13	0	1	0:05	0:11
123	11/4/93	19:14	19:16	19:19	0	1	0:02	0:05
124	11/4/93	19:16	19:20	19:21	0	1	0:04	0:05
125	11/4/93	19:35	19:38	19:42	1	2	0:03	0:07
126	11/4/93	19:35	19:40	19:43	1	3	0:05	0:08

Table 2. Continued

NUMBER	DATE	START TIME	PILOT DONE	END TIME	WORK ORDERS	CODE	PILOT TIME	DEBRIEF TIME
127	11/4/93	19:41	19:45	20:04	1	2	0:04	0:23
128	11/4/93	19:42	19:44	19:47	0	1	0:02	0:05
129	11/4/93	20:23	20:26	20:26	0	1	0:03	0:03
130	11/5/93	9:21	9:26	9:26	0	1	0:05	0:05
131	11/5/93	9:21	9:26	9:32	1	2	0:05	0:11
132	11/5/93	14:31	14:33	14:35	1	2	0:02	0:04
133	11/5/93	14:33	14:39	14:45	1	2	0:06	0:12
134	11/5/93	14:59	15:02	15:04	0	1	0:03	0:05
135	11/5/93	14:34	14:38	14:56	2	2	0:04	0:22
136	11/5/93	15:27	15:31	15:37	1	2	0:04	0:10
137	11/5/93	14:37	14:40	15:00	2	2	0:03	0:23
138	11/8/93	15:37	15:44	16:00	1	2	0:07	0:23
139	11/8/93	16:58	17:00	17:16	0	1	0:02	0:18
140	11/8/93	17:16	17:18	17:19	0	1	0:02	0:03
141	11/8/93	17:00	17:02	17:23	0	1	0:02	0:23
142	11/8/93	15:30	15:36	15:45	1	2	0:06	0:15
143	11/8/93	16:58	17:00	17:01	0	1	0:02	0:03
144	11/8/93	19:59	20:03	20:08	2	3	0:04	0:09
145	11/8/93	20:00	20:05	20:12	1	2	0:05	0:12
146	11/8/93	20:17	20:19	20:21	0	1	0:02	0:04
147	11/8/93	20:44	20:45	20:47	0	1	0:01	0:03
148	11/8/93	20:44	20:50	20:58	2	3	0:06	0:14
149	11/8/93	21:09	21:12	21:13	0	1	0:03	0:04
150	11/9/93	16:57	17:00	17:14	1	3	0:03	0:17
151	11/9/93	16:09	16:17	16:20	1	2	0:08	0:11
152	11/9/93	16:06	16:09	16:14	0	1	0:03	0:08
153	11/9/93	15:57	16:00	16:01	0	1	0:03	0:04
154	11/9/93	15:37	15:40	15:42	0	1	0:03	0:05
155	11/9/93	15:34	15:38	15:40	0	1	0:04	0:06
156	11/9/93	15:35	15:37	15:46	0	1	0:02	0:11
157	11/9/93	15:34	15:36	15:46	2	3	0:02	0:12
158	11/9/93	19:02	19:05	19:07	1	3	0:03	0:05
159	11/9/93	19:07	19:11	19:17	1	3	0:04	0:10
160	11/9/93	19:21	19:31	19:32	0	1	0:10	0:11
161	11/9/93	20:00	20:03	20:03	0	1	0:03	0:03
162	11/9/93	20:12	20:23	20:42	3	2	0:11	0:30
163	11/9/93	20:20	20:23	20:37	0	1	0:03	0:17
166	11/10/93	15:32	15:37	15:42	1	2	0:05	0:10
167	11/10/93	15:34	15:37	16:02	0	1	0:03	0:28
168	11/10/93	15:36	15:38	16:04	0	1	0:02	0:28
169	11/10/93	16:47	16:53	16:56	1	3	0:06	0:09
170	11/10/93	16:56	16:58	17:10	0	1	0:02	0:14
171	11/30/93	13:41	13:45	13:48	0	1	0:04	0:07
172	11/30/93	13:41	13:46	13:49	1	2	0:05	0:08
173	11/30/93	13:53	13:56	13:56	0	1	0:03	0:03
174	11/30/93	14:16	14:18	14:20	0	1	0:02	0:04

Table 2. Continued

NUMBER	DATE	START TIME	PILOT DONE	END TIME	WORK ORDERS	CODE	PILOT TIME	DEBRIEF TIME
175	11/30/93	13:53	14:03	14:22	1	2	0:10	0:29
176	11/30/93	14:15	14:22	14:36	1	2	0:07	0:21
177	11/30/93	14:22	14:27	14:37	1	2	0:05	0:15
178	11/30/93	14:30	14:34	14:53	1	2	0:04	0:23
179	11/30/93	14:17	14:37	15:21	2	3	0:20	1:04
180	11/30/93	14:59	15:04	15:27	2	3	0:05	0:28
181	11/30/93	17:08	17:09	17:13	0	1	0:01	0:05
182	11/30/93	19:02	19:12	19:40	1	2	0:10	0:38
183	11/30/93	19:23	19:27	19:44	1	2	0:04	0:21
184	11/30/93	19:46	19:52	20:02	0	1	0:06	0:16
185	11/30/93	19:43	19:55	20:11	0	1	0:12	0:28
186	11/30/93	20:00	20:04	20:17	0	1	0:04	0:17
187	11/30/93	19:19	19:39	20:42	3	2	0:20	1:23
188	12/1/93	13:40	13:49	13:49	1	2	0:09	0:09
189	12/1/93	13:43	13:47	13:56	1	2	0:04	0:13
190	12/1/93	13:42	13:47	13:57	1	2	0:05	0:15
191	12/1/93	13:44	13:47	14:08	0	1	0:03	0:24
192	12/1/93	13:46	13:47	14:10	0	1	0:01	0:24
193	12/1/93	13:52	13:58	14:12	1	2	0:06	0:20
194	12/1/93	14:22	14:26	14:31	0	1	0:04	0:09
195	12/1/93	14:32	14:34	14:36	0	1	0:02	0:04
196	12/1/93	14:33	14:38	14:41	1	2	0:05	0:08
197	12/1/93	14:36	14:40	14:43	0	1	0:04	0:07
198	12/1/93	14:55	15:00	15:04	1	2	0:05	0:09
199	12/1/93	14:56	14:59	15:09	0	1	0:03	0:13
200	12/1/93	14:56	15:00	15:11	2	2	0:04	0:15
201	12/1/93	15:44	15:50	16:00	1	3	0:06	0:16
202	12/1/93	18:56	18:59	19:00	0	1	0:03	0:04
203	12/1/93	18:56	19:00	19:05	1	3	0:04	0:09
204	12/1/93	19:06	19:12	19:15	0	1	0:06	0:09
205	12/1/93	19:04	19:10	19:16	1	3	0:06	0:12
206	12/1/93	19:18	19:27	19:32	1	3	0:09	0:14
207	12/1/93	19:30	19:34	19:36	0	1	0:04	0:06
208	12/1/93	19:38	19:42	19:45	0	1	0:04	0:07
209	12/1/93	19:39	19:42	19:50	0	1	0:03	0:11
210	12/1/93	19:36	19:42	19:58	2	2	0:06	0:22
211	12/2/93	19:44	19:47	19:50	0	1	0:03	0:06

The problems encountered during some of these debriefs centered primarily on the Core Automated Maintenance System (CAMS). In one case, CAMS rejected a debrief because the maintenance debriefer had not been notified of a tail number swap. Several other sessions reported that CAMS is slow, takes an extremely long time between screens, and does not accept input. These problems added to the overall debrief times because debriefer interaction was required.

Comparison of Debrief Results

A comparison of the data collected during the Debrief Test revealed some clear trends. Again, it is important to note that the data was not collected in accordance with a statistically valid experimental design; therefore, a comparison with any level of statistical significance is not possible. A summary of the comparison data can be found in Table 3, which lists average times and sample sizes for each categorization of the data.

Table 3. Comparison of Results

	IMIS		Current Method	
Debrief Time (All)	5:56	(45 debriefs)	13:26	(109)
Pilot Time (All)	3:57	(45)	4:36	(109)
Debrief Time (Code 1 Only)	3:15	(32)	9:36	(56)
Pilot Time (Code 1 Only)	2:58	(32)	3:26	(56)
Debrief Time (Code 2,3)	12:32	(13)	17:29	(53)
Pilot Time (Code 2,3)	6:23	(13)	5:50	(53)
Debrief Time (1 Work Order)	9:27	(11)	14:05	(37)
Pilot Time (1 Work Order)	5:05	(11)	5:19	(37)
Debrief Time (>1 Work Order)	29:30	(2)	25:23	(16)
Pilot Time (>1 Work Order)	13:30	(2)	7:00	(16)

Overall, the average debrief time using IMIS was less than half that using the current method (5:56 vs. 13:26). The average pilot time, considering all data, was also less, although the difference was not nearly as dramatic (3:57 vs. 4:36).

When considering only Code 1 debriefs (i.e., no discrepancies reported), the average debrief time is reduced by a factor of two-thirds when using IMIS (3:15 vs. 9:36). In these cases, the completion of the IMIS debrief requires only an additional 17 seconds after the pilot is done, as compared to the current method, for which an additional six minutes is required.

In debriefs where discrepancies were reported and work orders were opened, the average pilot time was not less when using IMIS compared to using the current method (6:23 vs. 5:50)

because the pilot was present as each work order was opened and as the appropriate entry from the FRM data was selected. The average overall debrief time for these debriefs was still less (12:32 vs. 17:29).

The times were similar when only a single work order was opened. However, due to the small number of debriefs where multiple work orders were opened using IMIS (only 2), no comparisons can be made.

User Feedback

The user feedback collected by the maintenance debriefs after the completion of the Debrief Test was valuable. The feedback indicated that the most liked aspect of the IMIS debriefing function is that conducting a debrief session for a Code 1 (no discrepancies) aircraft (A/C) is extremely fast, aided especially by the pre-filling of data elements from the flying schedule and by the availability of listers to select data and minimize data entry errors. Additionally, the enhanced question sets used when opening a work order were helpful to the debriefers when they were not qualified for or familiar with a particular discrepant A/C system. Thus, users believed that, with the enhanced question sets to assist in the debrief process, anyone can debrief a system. However, the enhanced question sets were also viewed as a somewhat negative factor because they require additional time in the debrief of the pilot for a Code 2 or Code 3 A/C.

The maintenance debriefers made several recommendations regarding functionality enhancements which would make the system even better, such as the ability to interactively update the enhanced question sets. The debriefers also noted that they must frequently update the debrief results in CAMS when new or revised information becomes available; by providing the capability to edit debrief data in IMIS after it has been accepted, the debrief process would become more efficient. Flying schedule and tail number swaps occurred frequently during the Debrief Test, and IMIS demonstrated a limited ability to respond to these last-minute changes. The debriefers believe it would be desirable to provide the capability to debrief a tail number which is not on the list of undebriefed sorties rather than wait for the change to be entered into CAMS and propagated to IMIS manually.

End-to-End Demonstration

The IMIS End-to-End Demonstration was a field demonstration of the primary functions of IMIS. This demonstration was conducted on F-16 Block 40/42 A/C assigned to the 310th Fighter Squadron (FS) at Luke AFB, AZ, from 1 June through 30 June 1994. It was intended to illustrate to users the overall IMIS concept by using the system to support a series of typical maintenance scenarios in an operational environment, under structured conditions. The demonstration showed system functional capabilities in all primary IMIS functional areas: debrief, diagnostics, electronic TOs, work order generation/close-out, and flightline management support.

The basic objectives of the End-to-End Demonstration were achieved with the validation of the IMIS concept. The demonstration showed that IMIS effectively provides information the managers and technicians require, provides information in a way that is acceptable to users, and is something users want. The participants also provided valuable feedback, including suggestions for improving the system and for improving the content and organization of data presented by the system.

A total of 32 participants, including expediters, production superintendents, maintenance debriefers, and technicians, completed the exercise. All the participants either were currently performing in the job they represented or had recent experience in that position. Data was collected from the participants using three different tools: an exit questionnaire, an automated questionnaire that collected opinions on IMIS functional characteristics, and the National Aeronautics and Space Administration (NASA) Task Load Index (TLX).

Exit Questionnaire Results

The exit questionnaire contains three direct questions and a place for the respondent to add written comments. The three questions are:

1. What did you like about IMIS as an aid to help you do your job?

2. What did you dislike about IMIS?

3. What changes would you make to improve the system?

The participants recognized that the current demonstration system is intended only for use in evaluating the concept of IMIS as a tool to establish requirements for a system to be developed for operational use. Consequently, they were able to evaluate the system on its potential. Overall responses to the questionnaire indicate a positive reaction to the IMIS concept. Many responses were very laudatory. The only exceptions were comments directed toward weaknesses in the demonstration system.

The following is a summary of the participants' responses to the question, "What did you like about IMIS as an aid to help you do your job?"

a. The large amount of information available through IMIS. Participants were impressed by the fact that, with a few key strokes, they could quickly access information which they would normally have to track down manually.

b. The currency of the available information. Participants liked the fact that not only are schedules and similar information kept current but that key people are notified of changes.

c. Not having to work with CAMS to extract or input data. IMIS automatically interfaces with CAMS and does not require the user to manually enter data into

CAMS. This was seen as a great advantage, in that this automatic interface could save time and provide more accurate information, for all maintenance personnel and the maintenance information management system.

d. Ready access to TOs. The availability of all required TOs on the Portable Maintenance Aid (PMA) was seen as a benefit because the technician will not have to carry a large number of TOs to the flightline or return to the shop for other TOs that may be needed.

e. Parts ordering. Both technicians and supervisors liked being able to access parts availability information rapidly through the PMA. They also liked the provision of notifying the production superintendent of a part order request and for getting his or her authorization for ordering the part.

The following is a summary of the participants' responses to the question, "What did you dislike about IMIS?"

a. Speed. Almost all participants mentioned speed as a problem for most maintenance management information support functions (times ranged from 35 to 90 seconds for data input and updating). However, respondents differed in their perception of the impact of speed. Some believed it could be quite important (". . . 30 seconds is a long time when 'the man' is looking over your shoulder"). Others saw the issue from a different perspective (". . . the time doesn't seem so bad when you consider that it would take me 15 or 20 minutes to track the same information today"). Another noted that "the availability of the information makes up for the slowness of the system."

b. Usability issues. There were several human/computer interaction procedures which some technicians found inconsistent. The primary problem was the use of the F1 and SELECT keys. In some cases, a selection was made with the F1 key; in other cases the SELECT key was used. The problem: it was not always obvious which key to use. The second most frequently mentioned usability problem was the confusion between the F1 and F8 keys when accessing TOs. IMIS uses F1 as the convention to approve data and continue with data processing. The TO presentation software, however, uses F8 to go to the next presentation. After using IMIS for a while, the user would become accustomed to pressing F1 to proceed. When using the TO presentation, the user then had to press F8 to proceed. It took time for the user to become accustomed to this change and the corresponding adjustment when returning to IMIS.

c. PMA keypad. Many participants encountered difficulty using the PMA keypad. The keypad requires a firm press; consequently, it was easy to think that it had been activated when it had not. Also, the PMA did not always respond immediately when the key was pressed, depending upon the amount of background processing occurring. When this happened, there was a natural tendency to immediately press the key again, which occasionally caused the user to miss a step or make a wrong selection.

d. Reliability. The PMA was prone to software failures during the End-to-End Demonstration. Most participants experienced at least one PMA crash during the session. Some of these failures were caused by known problems, while others were more difficult to identify. These problems were documented and most were corrected before the Fault Isolation Test was started.

Characteristics Questionnaire Results

The characteristics questionnaire consisted of 97 questions designed to measure participants' evaluations of various characteristics of the IMIS demonstration system. The questionnaire required participants to indicate the degree of agreement with a statement about an IMIS characteristic. The response was made on a seven-point scale. The complete questionnaire covered all key features and characteristics of IMIS. The rating scale used was from 1 (very positive) to 7 (very negative). Participants only responded to questions on features which they had experienced during the demonstration. Consequently, from the total of 97 questions, 41 were relevant during the End-to-End Demonstration. Some of these 41 questions were determined to have been incorrectly structured and were subsequently eliminated, reducing the total number of questions to 35.

Questionnaire results indicate that responses are generally consistent with respondents' answers to the exit questionnaire. Overall, responses were positive. The total overall rating for all responses was 3.01. Nineteen of the questions were classified as either very positive or positive. Three items were classified as negative (none were classified as very negative). Ratings for the remaining 13 questions were classified as neutral. A review of all the responses showed that the items receiving positive ratings include those concerning the manner in which information was presented on the PMA, procedures for accessing information, and techniques for interacting with the system. Most of the negative ratings related to the specific characteristics of the demonstration PMA, specifically the responsiveness of the keypad and the reliability of the Radio Frequency (RF) link. Specific features that were most favorably rated and areas identified as needing improvement are listed below.

The following features received the highest positive ratings (between 1.0 and 2.0).

a. Function keys were useful.

b. Training received was thorough.

c. Time permitted to become familiar with the PMA and its functions was adequate.

d. Spacing between the keys on the keypad was acceptable.

e. Turning on/off the RF devices from the menu was easy.

f. The size of the keys on the expediter's detachable PMA keyboard was adequate.

The following features received the highest negative ratings (between 5.0 and 6.0). It should be noted that no characteristic was rated between 6.0 and 7.0.

a. Determining how to proceed through the PMA screens was somewhat difficult.

b. Response time after pressing keys was somewhat slow.

c. Sending messages on the RF modem was somewhat unreliable.

The list of all 35 questions and their average scores is provided in Table 4.

NASA TLX Results

The NASA TLX is a multidimensional workload assessment tool designed to provide a measure of the workload imposed by a given job/work situation. The index is composed of weighted subscores of ratings on six factors which are believed to contribute to workload. The factors are mental demands, physical demands, temporal demands, own performance, effort, and frustration. The NASA TLX produces a workload measure for each factor plus a cumulative index of workload. Each index can range from 0 to 100 and represents a measure of the workload imposed by the job/work situation.

It is possible to measure the relative workload imposed by two job/work situations by having participants complete the NASA TLX for the same job performed under different work situations. This approach was followed for the End-to-End Demonstration to provide an initial indication on the impact of the IMIS on the workload of maintenance personnel versus the current paper-based system. Each participant in the End-to-End Demonstration completed the NASA TLX twice: once with the current paper-based methods of doing the job as the frame of reference and once with IMIS as the frame of reference. The paper-based ratings were based upon how technicians do the job now (based upon retrospection). The IMIS-based ratings were made immediately following the use of IMIS (based on current experience).

Complete NASA TLX ratings were made by 16 of the 32 subjects (data on the remaining 16 subjects was lost due to computer malfunctions and administration irregularities). Analysis of the ratings yielded a mean TLX workload index of 62.75 for the paper-based condition and 44.44 for the IMIS condition. The difference between means is statistically significant at the 0.9999 confidence level.

The results suggest that for this End-to-End Demonstration IMIS significantly reduced the workload experienced by expediters and production superintendents. However, caution should be used in interpreting the NASA TLX results because they are based upon a relatively small sample, and the paper-based ratings are based on retrospection rather than immediate experience. It should be noted that these findings are in the same direction as and reinforce early results from previous field tests showing more rapid job performance when electronic technical data is used in place of paper-based technical data. However, these conclusions remain to be fully validated when tested in an unconstrained operational environment.

Table 4. Characteristics Questionnaire Results

Characteristic (Response)	Average Score
When performing maintenance, the size of the text was (Easy to read – Difficult to read)	2.04
Highlighting information on the screen made tasks (Easier – Harder)	2.00
Accessing screens required to perform the task was (Easy – Difficult)	2.64
Determining how to proceed through the PMA screens in order to support your task was (Easy – Difficult)	5.90
Message lines (informing you how to proceed on to the next piece of information) were (Effective – Ineffective)	2.29
Function keys (F1 through F8) were (Useful – Not Useful)	1.48
Use of icons was (Easy – Hard)	2.47
Symbols chosen for icon pictures were (Effective – Not Effective)	2.05
Reliability of the IMIS machine that you worked with was (Very Reliable – Unreliable)	3.40
The training you received was (Thorough – Not Thorough)	1.50
Time permitted to become familiar with the PMA and its functions was? (Adequate – Inadequate)	1.86
The weight of the PMA was (Heavy – Light)	4.63*

* Inverse value of 3.37 used to allow lower numbers to reflect positive characteristic (lighter weight rather than heavier weight).

Table 4. Continued

The width and length (general shape) of the PMA were (Acceptable – Not Acceptable)	2.10
The prop or handle was (Effective – Not Effective)	2.20
The ruggedness of the keys on the keypad appeared to be (Acceptable – Not Acceptable)	2.90
Spacing between keys on the keypad was (Acceptable – Not Acceptable)	1.67
Pressing and activating keys on the keypad was (Easy – Hard)	3.80
Moving the cursor around the screen using the PMA arrow keys was (Easy – Hard)	3.35
The cursor moved where you thought it should (Always – Never)	3.13
Moving the pointer around the screen using the PMA thumb-knob was (Easy – Hard)	3.05
Response time after pressing keys was (Fast Enough – Too Slow)	5.22
The size of the PMA screen for displaying text was (Adequate – Not Adequate)	2.05
The size of the PMA screen for displaying graphical information was (Adequate – Not Adequate)	2.24
The PMA screen made information (Easy to See – Hard to See)	2.81
Ability to see and read the screen contents from various angles was (Easy – Hard)	4.64
The screen was readable at (Many Angles – Limited Angles)	3.70

Table 4. Concluded

Glare on the screen affected performance on the task (Not At All – A Great Deal)	4.09
The back light was (Helpful – Not Helpful)	4.93
The brightness of the back light was (Good – Bad)	3.29
Sending messages on the RF modem was (Reliable – Unreliable)	5.94
Turning off the RF device from the menu was (Easy – Difficult)	1.44
Messages sent by RF link were responded to (Quickly – Slowly)	3.88
The IMIS automatic status updating would reduce the chatter on "bricks" (A Great Deal – Not At All)	2.00
The size of the keys on the expediter's detachable keyboard was (Adequate – Not Adequate)	1.83
Limited descriptions in the discrepancy field of the work order form had (No Impact – Negative Impact)	4.11

Other Activities/Results

The PMA RF capability was tested by transmitting and receiving messages from the PMA to the IMIS base antenna located on the 310th FS hangar (Building 913). Transmissions were made at distances of up to 2500 feet (762 meters), sufficient to cover the 310th FS A/C parking area. No problems were encountered in transmitting messages at these distances. In addition, the RF capability was tested with up to four PMAs sending and receiving. No problems were encountered. However, it became apparent that the more PMAs in operation, the slower the transfer of messages between the PMAs and the base station. Also, using the RF slows down non-RF-related processes on the PMAs because the PMA has to interrupt ongoing processes to receive messages and updates.

The PMAs were installed in the expediter vehicle and tested without problems. A PMA was also installed in the production superintendent's golf cart but was not used for transmissions. Some minor modifications for the mounting racks were identified.

The PMA was not formally tested for heat tolerance during the End-to-End Demonstration. However, it was used under high-temperature conditions. It was used in an expediter truck without air conditioning in ambient temperatures up to 117°F (47°C). In addition, it was used in a hangar environment for several hours per session in temperatures up to 110°F (43°C). No problems were encountered with the PMAs due to heat. This is a significant finding because heat tolerance had previously been a concern.

Fault Isolation Test

The detailed results from the Fault Isolation Test are documented in separate Armstrong Laboratory reports (AL/HR-TP-1995-0033 and AL/HR-TP-1995-0034).

CONCLUSIONS

The conclusions reached as part of the IMIS field tests and demonstrations are documented in the following subsections.

Debrief Test

The debrief process was much more efficient using IMIS as compared with the current method because of the smaller number of screens accessed and because the user's direct interface with CAMS had been eliminated. This was especially true for the Code 1 debrief sessions during which no work orders were opened. In addition, the amount of time the pilot was involved did not increase, despite the fact that the maintenance debriefer entered the information into IMIS with the pilot present (in contrast to the current system, where the debriefer often waits until later to enter the information into CAMS).

The users also preferred the IMIS user interface features like pre-filled data and listers. The enhanced question sets also provided the capability for any maintenance debriefer, regardless of experience level or Air Force Specialty Code (AFSC), to ask technical questions about the discrepant system and enter the descriptive discrepancy information based on the pilot's observations.

End-to-End Demonstration

The End-to-End Demonstration showed that IMIS is capable of providing maintenance personnel with both the management and technical information they require. Both the quantity and the currency of information exceed the data currently available to them. However, the system response times and reliability need to be improved in order to enhance user efficiency.

The ability to enter data into a single system and have that system send the data to the necessary legacy databases is a very desirable feature. Eliminating the unique database interfaces will reduce the time the maintenance personnel spend interacting with the legacy databases.

A seamless interface between the various software processes must be developed. The transition from the IMIS to the TO Presentation (TO Present) software was apparent to the user and was magnified by the differences in the user interface. The user interface must be made consistent throughout the system.

Fault Isolation Test

The field test successfully demonstrated the feasibility of the IMIS concept and the potential benefits of developing the system for operational Air Force use. The test provides strong evidence that IMIS can enhance the performance of maintenance technicians performing on-A/C maintenance.

Technicians were able to complete fault isolation and repair problems with greater accuracy, in a shorter time, and with fewer errors and fewer parts used in the process. The improved performance will significantly reduce the time required to return an A/C to operationally capable status, provide for more effective utilization of available personnel, and reduce expenditures for procuring, repairing, and stocking A/C replacement components.

The test also showed the advantages of the IMIS RF link. During the Fault Isolation Test, the RF was used for ordering parts and transmitting work order close-out information which was the major contributor to faster job completion. The End-to-End Demonstration showed the advantages of the IMIS RF capability in supporting flightline maintenance managers in a variety of ways, including providing up-to-the-minute A/C and maintenance status information and offering the capability to make personnel assignments, open and close work orders, and communicate with other maintenance managers.

The Fault Isolation Test demonstrated that IMIS is easy to use and is preferred by technicians. The technicians had very little trouble using IMIS after a short training session. Both the specialist and APG technicians were able to perform the test tasks with minimal difficulty. In contrast, the APG technicians (and some specialists) experienced significant difficulties in using the paper TOs.

More detailed Fault Isolation Test conclusions are documented in separate Armstrong Laboratory reports (AL/HR-TP-1995-0033 and AL/HR-TP-1995-0034).

LESSONS LEARNED AND RECOMMENDATIONS

The IMIS field tests and demonstrations proved to be a valuable source of information regarding the IMIS concept and implementation. In addition, the experiences over the entire life of the program provided information in many different areas. The lessons learned and resulting recommendations regarding the hardware, software, system, functionality, human factors, data, and programmatics are described in the following subsections.

Hardware

The lessons learned and recommendations regarding the PMA, Maintenance Information Workstation (MIW), and Aircraft Interface Panel (AIP) are summarized in the following subsections.

Portable Maintenance Aid (PMA)

The overall weight and dimensions of the PMA were found to be acceptable by the users. There were no complaints about the device being too heavy. Although the length of the PMA was within specification when used in the cockpit during the Fault Isolation Test with the handle fully extended, it occasionally obstructed several instruments. Possible reductions in the length of the PMA should be investigated.

The PMA handle hinges experienced some durability problems. The oscilloscope-type ratchet joints were not designed to withstand substantial weights and were not force-synchronized (i.e., it was possible to turn one and not the other). Additional reinforcement should be provided to make the handles sturdier. In addition, the movement of the handle was restricted somewhat by the RF antenna and the connectors. If the antenna were hinged, the handle could be fully extended without interference. This would also allow the antenna to be adjusted to enhance reception. Other locations for the connectors should be considered as well.

The PMA strap was used only sporadically during the field test because additional personnel were available to assist the technician in taking required equipment to the A/C. The use of the strap should be evaluated further to determine its usefulness.

The tethers for the protective caps for the PMA connectors (external power, keyboard, 1553, etc.) broke easily. A sturdier mechanism should be used to attach the caps to the connectors.

There are two 1553 interface cables for the PMA; each cable has the same connector. Using the same connectors allowed the technician to connected the cables into the wrong port resulting in misidentification of the discrepancy. With the small number of pins actually used, it would be feasible to combine the two channels in a single connector to eliminate confusion.

A close-fitting right-angle connector (or another type of connector which does not stick straight out from the case) should be considered for the external power connector. This would reduce the likelihood of damage to the connector or the PMA if bumped and would reduce the space occupied by a plugged-in PMA. This was especially a problem when multiple PMAs were being charged at one time. A rack in the support area with which several PMAs could be docked to charge their batteries could be developed.

The PMA power switch is a two-position, standard toggle switch which is not entirely recessed and has the potential for being inadvertently turned off. In a UNIX environment, where

improper shutdown of the PMA may corrupt the file system, a totally recessed locking toggle switch or guarded toggle switch should be considered.

Navigation using the thumb knob on the PMA was not viewed favorably by users. The select function was sometimes inadvertently activated when the user intended to move the cursor. A pen-based or touch-screen user interface (or possibly other pointing devices which have become available) should be considered, especially for the flightline expediters' devices. This would be particularly useful on the PMA's virtual keyboard, rather than the awkward navigation and selection using the arrow and function keys.

The 3/4" keys and 1/4" spacing required by MIL-STD-1472 limited the number of keys which could be on the PMA and may have an impact on future PMA dimensions. Tailoring of MIL-STD-1472 requirements to allow smaller keys and narrower spacing could provide space for additional keys or allow the dimensions of the PMA to be reduced if no additional keys are necessary. In addition, it was sometimes difficult to tell whether the bubble dome type keys used on the PMA keypad had responded to a key press; thus the user would press the key numerous times. The tactile feedback provided by the keypad did not guarantee that electrical contact had been made. Lowering the resistance in the keypad, thereby reducing the force required to press the PMA key, could also enhance key activation.

The battery life was between 2.5 and 4 hours, which was adequate for most diagnostics tasks. When batteries were not allowed to discharge fully before recharging, "memory effect" problems were experienced due to the properties of the nickel-cadmium battery pack. Periodic reconditioning restored many of the batteries to a useful charge life. The lack of adequate time between the time a low-battery warning appears and the time failure occurs, another characteristic of the nickel-cadmium batteries used, might dictate the use of a battery having a more gradual discharge rate at the end of its cycle. Other rechargeable battery technologies (such as nickel-metal hydride or lithium) should be evaluated.

PMA battery replacement was awkward. The captive screws which held the cover in place were very small, and the cover was not hinged or otherwise fastened to the body of the PMA. Some non-volatile memory, which would allow the PMA battery to be changed without having to shut it down all the way, would be desirable.

High temperatures and direct sunlight affected the readability of the PMA display, which would become darker. The adjustment of contrast via software accessible through the main menu bar is not adequate if screen visibility has already deteriorated to the point where the screen is unreadable. The contrast adjustment should be on the PMA box itself. In addition, glare and off-angle visibility need to be improved. Displays considered for future PMAs should undergo thorough evaluations and tradeoffs considering these factors as well as cost and power.

The PMA would have benefited from a more modular design regarding maintainability, upgradeability, and testability. A production PMA should include test points or ports and a modular design such that each of the major components could be removed and replaced independently for maintenance and upgrades.

Maintenance Information Workstation (MIW) and Memory Module Loader (MML)

The MIW and MML were viewed very favorably, with minimal problems experienced. Use of commercial off-the-shelf (COTS) hardware was the most efficient solution for these hardware devices.

Aircraft Interface Panel (AIP)

The AIP implementation can range from an on-board PMA-like device to simply providing surface access to the data bus controller. For the F-16, it would be adequate to provide access to the 1553 bus controller via a surface attachment. If maintenance is done in an isolated environment, it may be better to have an on-board PMA-like device which can be used to display TOs, Job Guides, checklists, and so forth, thereby eliminating the need to have a PMA available.

Software

The screen-based CAMS interface was inefficient and susceptible to frequent interruptions due to minor software changes. A standard legacy database interface, which might require changes to both CAMS and IMIS, should be developed. A better method would utilize Structured Query Language (SQL).

Information regarding updates to CAMS was not disseminated in a timely manner to the organizations which needed access to that information. The format in which this information was received also resulted in additional time and effort spent communicating the changes to the subcontractor. In addition, limited information was available to assist in understanding all the data elements and values used in CAMS. For a fully implemented CAMS interface, the development of a CAMS data dictionary, in which all attributes, values, and error messages are defined in detail, would be required.

Modem connection should be available between all software development and test sites. The connection provided a very efficient mechanism for remotely troubleshooting software and testing the CAMS interface without being at Luke AFB.

The demonstration system was saturated by the RF messages sent to a relatively small number of PMAs. To support messaging in an unconstrained environment when dealing with the number of PMAs required to support an entire FS, a mechanism for filtering messages may be required. Improving the efficiency of parsing the messages into the database would also help alleviate this problem.

The tools that were selected for the software development environment were not sufficiently mature to support the functional and performance requirements. Throughout software development, various bugs and limitations were encountered, with very few quick fixes. A more extensive analysis of the available tools and platforms should be conducted before beginning implementation.

The Santa Cruz Operation (SCO) UNIX, selected as the PMA operating system, was not as standard as originally believed. Upgrades to other tools could not be made without undergoing an additional process to re-host under SCO UNIX (often at additional cost). Choosing a second operating system also resulted in additional effort to recompile source code and to test and fix platform-specific problems.

The design used for this demonstration implementation was not developed in as modular a fashion as would be expected for a production system. Direct calls to the database and the Graphical User Interface (GUI) tool are found throughout the application code, so that when a change to a specific database or GUI call was needed, a time-consuming search of the code for these calls was required.

Field experience with the PMAs has generated concern over performance of the current 80X86-based architecture, in spite of two processor upgrades. Performance requirements should be determined early in the design process so that the appropriate processor and system architecture can be chosen. System performance, although not always a requirement, is always an issue.

Aural and more attention-getting visual alerts regarding incoming messages should be available on both the PMA and the MIW, especially for time-critical messages for certain users like the expediters or the production superintendent. The display of the message icon did not provide adequate notice to the user that a message had been received.

Separate databases containing the diagnostics and TO data for each subsystem were inefficient. The technician was able to perform diagnostics tasks for only a single subsystem. If the technician needed to perform another diagnostics task on a different subsystem, they had to return to the support section to check out a new cartridge. This also required that multiple databases on the MML be updated and maintained. It would be better to provide all diagnostics and TO data on each cartridge or to provide a broader set of subsystems to be supported by a single cartridge.

The 1553 interface, as implemented, was inefficient in that every new communication had to be developed and tested for each subsystem. The preferred solution would be to have the PMA recognized as a remote terminal device by the bus controller's Operational Flight Program (OFP).

The "Back" capability (ability to back up to a previous step or screen) should be implemented throughout, both in IMIS and in TO Present. However, the backward navigation implemented in TO Present displayed messages pertaining to software states which were not relevant to the user. These messages should be removed or replaced with messages that are pertinent to the back-up sequence.

The TO Presentation system should allow the user to view more than just the current step. The display should include prior and upcoming steps, with the current step highlighted.

Actuation of the "F8 Next" function key would then move the highlighted area to the next step. A "review" capability, which would allow the user to review any step in the entire task without changing the state table values, should also be considered.

When displaying TO input conditions, such as number of people, support equipment, and consumables required, these conditions should be grouped on a screen. Placing each of these items on a separate screen reduces the technician's efficiency.

Utilities to perform certain database changes (such as updating the list of A/C or personnel) would have provided a much faster mechanism for updating databases. With the current software, many of these changes could only be done by building a new database, a process which takes a significant number of hours between creation and testing.

More automation of the software installation process would have been beneficial. With the frequent field updates, there were often problems with having the correct versions of all the files available. Automating this process would have eliminated many of these errors.

System

Wireless communication is required for an effective maintenance operational environment. Without wireless communication, flightline managers would not have the most current information available to perform their tasks. The entire A/C maintenance area must be supported by wireless communication. RF coverage was adequate for the flightline area but was inconsistent in the hangars, where it was also required. Providing large area coverage may require the use of repeaters.

Security issues are a potential problem for a system which has access to classified data. Use of classified TOs on the PMA, when a user does not always maintain constant possession of the PMA, needs to be addressed. This will also be a problem for displaying classified data on the MIW in areas that are not adequately controlled.

Functionality

The lessons learned and recommendations regarding the functionality in each IMIS functional area are described in the following subsections.

Startup/Shutdown

The text shown by the operating system during startup and shutdown should be hidden from normal PMA users. It should be available on request to system administrators and software engineers. In addition, the user should not have to respond to any prompts when starting up or shutting down the PMA. The RF should always be turned on; the user can turn off the RF, if desired, after logging in. This would make the startup and shutdown procedures less confusing for the user. Also, the software control of the backlight intensity when bringing up and shutting down the PMA was limiting. The user could not always see the displayed text.

The users also expressed a desire to have an indication of whether their assigned PMA is fully functional. The results of the PMA's power-on Built-In-Test (BIT) could be reported to the user, just prior to the IMIS Login screen, to provide this information.

Login

The users noted that they normally access the same information each time they log onto IMIS. Displaying the most frequently used screen for that particular duty title immediately after logging on could be more efficient than requiring the user to select the menu item. For example, airplane general (APG) flightline expediters would want to see the FS A/C Status, while maintenance debriefers would want the list of undebriefed sorties shown prior to performing debrief.

The "Welcome to IMIS" screen following Login which provides the name as "Smith John Z" should be changed to include the user's rank and last name only (e.g., Sgt. Smith).

Menu Bar

When in TO Present, menu accelerators (i.e., using numbers to select menu items) were available. The users found this to be a desirable feature which they recommended should be available throughout IMIS, not just in TO Present. This could also be expanded for application to data listers.

Prepare/Extract PMA Cartridge

Creation of a PMA cartridge should be based on a specific technician assigned to work on a specific discrepancy, not on a subsystem list. This could be accomplished by providing to the support personnel at the start of Prepare PMA Cartridge a list of open work orders (to include the assigned technician and scheduled start time) for which a cartridge has not yet been prepared. The work unit code (WUC) of the work order would then be used to identify the corresponding subsystem to be worked. This process would also assist in identifying who has been assigned to each PMA, a manual process in the current system.

The Extract PMA Cartridge Data function should include retrieving audit trail data recorded during a diagnostics session and storing it on the MIW for further analysis.

Task Assignment

There were several aspects of the Task Assignment display in terms of usability and readability which the users found could be improved. For example, deletion of a user's final task assignment should not delete the user's name from the display, and repetition of a person's name when that person is assigned multiple tasks makes the display unnecessarily difficult to read. They also suggested that the display include the time the assignment was made and the time the work was started (for work orders only).

When assigning tasks and requesting the list of job control numbers (JCNs), the unassigned JCNs for that manager should be displayed first on the list. Currently, all open JCNs are displayed, resulting in a very lengthy list. Reading this list would also be easier if the A/C tail number and WUC were provided along with the JCN.

If the person for whom a task assignment change has been made is currently logged in, that person should be notified of the change via a message. This will help users keep informed of task assignment changes that affect them.

The capability to display a list of open work orders assigned to a particular work center or aircraft based on the WUC should be provided. This information would allow a manager to know what other tasks are currently in work and whether the current assignments should be reassigned to accommodate an incoming work order.

Certification roster information should be readily available (i.e., by pressing a single function key) when making task assignments to check personnel qualifications against the specific task. This would be beneficial information to have available when deciding which individual should be assigned to a particular task.

Expediters who update the task assignments should be able to see and update only the personnel in their work center and on their shift. The production superintendent and flight chiefs should have the ability to update and review all personnel assignments for their work center.

Certification Roster

The certification roster is currently a read-only display. In an operational environment, it should be possible for the authorized personnel to make certification roster updates in IMIS and transmit the changes to the appropriate legacy systems.

In addition to displaying the certification roster by person, the capability to select a qualification and list all personnel who have that particular qualification should be provided. This would be useful in making task assignments. Certain certification data (e.g., clearing a red X, back ordering a part, or performing an engine run) may need to be available during the task. This data could be inserted into the technical data or have a soft key to bring up the certification roster.

Aircraft Status

The APG expediters, specialist expediter, production superintendent, and munitions expediter will all want to record remarks on the status screen. The remarks field should be made editable for them to record their own notes for each A/C. This data may need to be saved from one day to the next.

When assigning an A/C to a location, the user is not prevented from assigning it to a location already occupied by another A/C. Some locations allow only a single A/C, while others (e.g., Wash Rack) can accommodate multiple A/C. IMIS should automatically check this data for potential conflicts and alert the user of any found.

The only status attribute values that were used were fully mission capable (FMC), partially mission capable (PMC), and not mission capable (NMC). The rules for the use of the other status codes which provide information about the cause of the status (i.e., supply, maintenance, or both) should be automated. An example of this would include updating status to not mission capable - supply (NMCS) when a required part is back ordered.

Status information is most current in IMIS, not in a legacy database. IMIS should transmit A/C status updates to the legacy database to ensure that the most up-to-date information is available in both systems.

A/C estimated time in commission (ETIC) should consider only those work orders which have a grounding discrepancy (symbol of X). Currently, the ETICs of all work orders open against an A/C are used to determine the overall A/C ETIC. When the last work order with a symbol of X is closed, the A/C ETIC field should be blank.

The specialist expediter, munitions expediter, and production superintendent need to be able to review status for all A/C in the FS (not just A-Flight or B-Flight). Upon selection of the FS A/C Status menu item, it would also be more efficient to display the most frequently used option rather than provide a choice. The A-Flight APG expediter would normally view the A-Flight status, the B-Flight APG expediter would normally view the B-Flight status, and the other maintenance managers would review the status of all A/C. The Different Organization function key could be used if a user wants to display data for a different set of A/C.

Maintenance Operations Center (MOC) users require the capability to view data for all squadrons in the wing, although much of that data may be preferred on a squadron-by-squadron basis. The "Different Organization" hierarchical listers must include choices appropriate to users throughout the wing and should be tailored to the specific user.

When a technician requests fuel for a particular A/C, IMIS currently sends a message to the appropriate APG expediter, who must then manually notify the MOC of the fuel request. Upon acknowledgment of the fuel request message by the APG expediter, IMIS should send a message to the MOC indicating which A/C needs fuel and the location to which the fuel truck should be sent.

The use of the mail icon for processing fuel requests, exceptional release requests, and status change requests may become a burden for the APG expediter. The use of a visual indicator on the status screen (making the "Crew Ready" field flash when an Exceptional Release has been requested, for example) might allow the expediter to process the information more efficiently.

The placement of information on the different duty title-based FS status screens was made as standard as possible. Since the user must scroll to view all the information available, it would be better to tailor each screen by user group to display the information accessed most often by each group. This will reduce the amount of scrolling required to present users with the information they use the most.

The FS A/C Status screen needs to be read-only for the technician. The technician needs only to be allowed to recommend a change to the ETIC for a single A/C, which should be done through the Individual A/C Status screen.

The Configuration Code lister is not conducive to making single changes to an A/C's configuration. To make any change to the configuration code, the user must repeat all the hierarchical steps, including those which have not changed. Options for making this more efficient should be investigated.

There should be a relationship between the navigation pod and targeting pod information and the configuration code. A change in the navigation and targeting pod information should cause an update to the configuration code (and vice versa). The presence or absence of these pods can be traced to the first character of the configuration code.

The number of days since the last flight should be automatically computed and updated based on each day's actual sorties flown, as recorded by IMIS. It will be very time-consuming for the user to determine this information manually.

The MOC's sortie summary (available through the FS A/C Status screen) should reflect the flying schedule and debrief information available each day. The totals should be reset as appropriate at the start of each day.

ETIC and status updates for all A/C are sent to the production superintendent and the appropriate APG expediter. These updates should also be sent to the specialist expediter and the munitions expediter.

Debrief

After completing a debrief, the user should return to the list of undebriefed sorties, not the main menu bar. The maintenance debriefers will normally conduct several debrief sessions in a row, and this change would allow the debriefer to begin the next debrief more quickly. Once all sorties had been debriefed, a message to that effect would be displayed prior to returning the user to the main menu bar.

There is currently no capability to edit debrief information within IMIS after the maintenance debriefer finishes the debrief and prints the sortie recap (which also causes the debrief data to be sent to the legacy system). If incorrect information is provided (or if the information changes following debrief), the user must currently use CAMS to edit the debrief data. IMIS should provide access to a specified amount of debrief data (one or two days,

possibly) for editing and re-transmission to CAMS. This could also provide the capability to reprint the sortie recap in the event there was a printer failure when the recap was originally sent to the printer.

No capability was provided to debrief an unscheduled sortie. This option should be provided to allow debriefing of unscheduled sorties and sorties for which flying schedule changes have not yet been entered.

The users requested that the Julian date and local time be displayed at all times. This would be especially valuable during debrief.

The scheduled take-off and landing times were not included in the debrief display. Consequently, debriefers sometimes canceled out of debrief transactions to ensure that the data entered would not result in a sortie deviation.

When opening a work order during debrief, the ETIC and scheduled start date and time should be left blank (or deleted entirely from the display). The maintenance debriefer does not have the necessary information to assess when the task will start and how long it will take to complete. The expediter will be able to make this determination when the task is assigned.

Pilot Call-In

Depending on the base, the pilot call-in information may actually be received by the FS Operations Center personnel or by the MOC. An MIW needs to be available in the FS Operations Center to support entry of pilot call-in data.

Minimum Essential Subsystem List

The Minimum Essential Subsystem List (MESL) is currently a read-only display. When the MESL needs to be updated, password-controlled changes by authorized users should be allowed.

Work Order

The status changes which are recommended by IMIS upon the opening or closing of a work order should take the MESL and the next scheduled mission for the A/C into account. Currently, the status is based strictly on the symbol for the work order (X causes the A/C to be NMC, while / causes it to be PMC).

The WUC should be displayed more prominently on the Open Work Order screen. The WUC can also be used to determine which work center the task should be assigned. Once the fault code is known, this may provide information driving a change to the ETIC.

The When Discovered Code (WDC) should be validated against the debrief data (if opened during debrief) and the flying schedule. For example, if the WDC indicates that the

discrepancy caused an air abort, the debrief for that sortie should reflect the same information. Also, if the discrepancy is discovered several hours before the scheduled sortie, the WDC should be consistent with this fact.

The assignment of a work order to a technician should be based on both qualification and availability. When the expediter receives the open work order notification, it would be helpful to have access to a list of technicians within that expediter's organization who are qualified, with an indication of whether each is currently available. If there are no qualified technicians available, the expediter would have the option to schedule the work order for a later time when the technician is available or to select a technician who is currently assigned to a different task and juggle the task assignment schedule.

The opening of certain panels requires that additional work orders be generated. IMIS could increase the efficiency of the maintenance process if these work orders could be opened automatically when the corresponding step in a TO is accessed or completed.

The Performing Work Center (PWC) field should not be editable on the Update Work Order screen. If the PWC needs to be changed, the technician should generate a Work Center Event (WCE), not update the work order.

The Work Order History display should also include the Action Taken code, How Malfunctioned code, symbol, WDC, the person who closed the work order, and the person who inspected the work.

The Work Order History displayed should be based on a match of the entered characters of the WUC, not all five characters. When the work order is opened, only the first three characters are typically known (e.g., 74A00), while the closed work order will have more detail in the WUC. A match of the open work order WUC to closed work order history WUCs can occur only if the number of WUC characters compared is the same for the closed work orders as is known for the open work order or specified in the query.

The closed work order notification should also be sent to the person in charge of the organization to which the work order was assigned (e.g., the specialist expediter should be notified when a work order assigned to the Avionics Section is closed). This will provide the expediter with information about the availability of personnel.

Information regarding removed and installed part and serial numbers obtained during diagnostics should be automatically pre-filled for the closed work order. Ideally, this information would not even have to be entered during diagnostics (the information for the removed part could be determined from the A/C, while the information for the installed part could be provided by supply).

Red X assist messages should not always be sent to the APG expediter. When the WUC of the work order is for an avionics subsystem, the Red X assist message should be sent to the specialist expediter. Additionally, when the APG or specialist expediter receives the Red X

assist message, he or she should be able to display a list of personnel who have the necessary qualifications, select a name from the list, and send a message to that person, indicating the A/C tail number and location to which that person should report.

Entering multiple criteria (A/C tail number, performing work center, or JCN) for identifying a work order to be closed or updated resulted in a dramatic increase in the amount of processing time. The method used to search the database for work orders meeting these criteria should be examined to determine how this can be made more efficient.

Schedules

The specialist expediter, munitions expediter, and production superintendent need to be able to review the flying and maintenance schedules for all A/C in the FS (not just A-Flight or B-Flight). Upon selection of any of the schedule menu items, it would be more efficient to display the most frequently used option rather than provide a choice. It was believed that the A-Flight APG expediter would normally view the A-Flight schedules, the B-Flight APG expediter would normally view the B-Flight schedules, and the other maintenance managers would review the schedules of all A/C. The Different Organization function key could be used if a user wanted to display data for a different set of A/C.

Adding a tail number to the flying schedule involves coordination among the production superintendent, MOC senior controller, the FS Officer-in-Charge (OIC), operations programmers and top-level management personnel, weapons storage and weapons flight personnel, and the Squadron Plans and Scheduling office. These personnel are required to sign an Air Force Form 2407. IMIS should assist in coordinating the flying schedule change and obtaining approval from the necessary parties before updating the database to reflect the change.

IMIS should have the capability to create and update schedules and send this information to the legacy database. Currently, IMIS can only receive this information from CAMS, even though IMIS may have more up-to-date information.

The list of events displayed on the Maintenance Schedule should be dynamically determined from the maintenance requirements found in the time distribution listing and on Air Force Technical Order (AFTO) Form 781K. IMIS currently displays a fixed set of event types which appear regardless of whether any A/C has been scheduled for that activity. More automation should also be introduced in scheduling A/C for periodic, regularly scheduled maintenance actions.

Troubleshooting

The Troubleshooting Started message sent at the beginning of the diagnostics task should include the time started and the assigned technician, in addition to the A/C tail number and JCN. Without this additional data, the expediter receiving the message will not have enough information about what is being done to each A/C.

The ability to review parts status and to review messages while in TO Present is essential. Although messages can be received and displayed while in TO Present, the message icon does not appear, so the user is not made aware that a message (often a part status message) has been received.

The existing bookmark capability cannot be used to annotate problems with the TO data for use in filling out an AFTO Form 22, since the bookmark is not saved after the diagnostics session is closed. The capability to save such a bookmark to allow the AFTO Form 22 to be generated at a later time, on the MIW, would be desirable.

The diagnostics functionality provided (change test results, list of actions taken, rankings of tests/repairs/actions, etc.) was valuable to technicians and helped make their job more efficient. In addition, it was useful to display the recommended best action prominently and allow that procedure to be initiated via a single keystroke, since this was the option most frequently selected.

Technicians should not be given the option to work on JCNs that are not assigned to them. Currently, users are notified at the beginning of troubleshooting when they have no tasks assigned to them and are given the option to select from other work orders. This capability should be eliminated.

The dialog box which asked the technician if enhanced diagnostics should be used was confusing for most, in that they were told to respond with "F2 No." This dialog box should be reworded to define more clearly the consequences of each response, and the response which will be selected most frequently should correspond to F1.

Parts

Having part availability information when ordering a part through diagnostics was valuable. This information should also be provided when ordering a part outside of diagnostics. At a minimum, the software should check to see if the latest inventory levels from the Standard Base Supply System (SBSS) show whether that part is in stock. If there appears to be none in stock, the technician should receive a message stating this and should be given options regarding how to proceed (e.g., call production superintendent).

Although the Quick Reference List (QRL) is not used at all bases, the users at Luke AFB liked having the electronic version of the QRL and found this to be an efficient mechanism for ordering the most frequently needed parts.

Since all part orders are authorized by the production superintendent (and supply personnel do not assist in filling out the appropriate forms), additional information regarding the different data elements on the part order screen (Urgency Justification code, Transaction Exception code, Mission Capable code, priority, etc.) and their values must be available to allow the production superintendent to provide correct input on the part order, not just to enter his or her password.

The Illustrated Parts Breakdown (IPB) should begin with a subsystem graphic or series of graphics and use hot spots to allow various components to be selected. Upon selecting a component which can be ordered, the textual part information associated with that part would be displayed. If that component can also be further broken down into other components which can be ordered, these hot spots should also be available for selection.

The users emphasized that cannibalization was very important in the overall part-ordering process. This should be one of the areas considered for implementation in future development phases.

The ability to perform a defective part turn-in and generate the AFTO Form 350 tag should be possible from the flightline. Currently, this capability is available on the MIW only (since printing is involved). Ideally, this information would then be available when the work order is closed from the flightline, allowing the Tag Number field on the Close Work Order screen to be pre-filled.

Messages

When sending a message, a list of standard narratives with commonly used messages pertaining to that user's duty title should be available in addition to the free-form text input. This would save the user considerable time, especially if a message is being created on a PMA without a keyboard.

The display of messages one at a time (and being forced to select the message icon or the Display Messages menu bar option repeatedly) was cumbersome for the user. The capability to display an index of all unread messages (to include who sent the message, date/time sent, and type of message or message subject), listed by priority, should be provided. This will allow a user who receives a lot of messages to select the high priority messages that need to be responded to most quickly.

Notifications which are sent to various personnel are based on their duty title and shift, regardless of whether they are logged on or even working that day. These messages need to be sent to the people who are available and authorized to provide the necessary response. In addition, if one authorized user does not respond within a specified amount of time, the message should be rerouted to another authorized user who is available.

Human Factors

There was a high degree of user acceptance of IMIS despite the significant change that the system introduced from the way the maintenance process is currently performed. Early involvement of the users in both hardware and software design was critical in gaining user acceptance.

Consistent placement of the cursor and consistent first focus are necessary for the user to readily identify where the cursor control resides. There were some cases when the user did not know where data was being entered or where the cursor was even located as a result. The loss of focus was a problem in TO Present where the user had to recognize that focus had been lost then move the pointer to regain focus.

Visual cues need to be more apparent (and consistent) when processing. The hourglass was difficult to see and did not always appear immediately. A dialog box might be more effective in certain cases where there is a lengthy wait. This would help the user avoid pressing keys inappropriately when there is some uncertainty about the status of the processing.

The content of the message line was often inadequate to instruct the user of the possible actions which may be taken on a given screen. In some cases, no message was presented at all. The instructions to the user need to be made clearer.

The screen format for scrollable displays, particularly the spreadsheets, made it difficult for users to know when scrolling would be appropriate or what would be displayed if they did scroll. It sometimes appeared that the entire spreadsheet was already displayed, when in fact there were more rows or columns available. The manner in which scrolling was performed on the PMA was also awkward. It should be noted that the End-to-End Demonstration did not provide the users of most of the spreadsheet displays (e.g., the expediters and production superintendent) any extensive practice in using them in a realistic context. This should be further evaluated before recommending changes.

Data

Skill levels (expert and novice) need to be implemented more extensively in the data. Experienced users felt that much of the information that was presented on the expert track was unnecessary.

The ability to update data, change weights and times, and update question sets should be provided, assuming adequate controls can be introduced to prevent use of unvalidated data. These controls must include determining who the appropriate personnel are for updating this data and where these changes can be made.

Validation of the TO data is a significant issue because it is very time-consuming and must be repeated each time new data is received or data is changed. There is currently no mechanism in place for validating electronic TO data. Validation of the data for use in an unconstrained environment will be extremely costly for those procedures which have resequenceable steps or which have many branches to be checked. The validation of data which is not resequenceable (e.g., work cards or remove/replace procedures) will not be as difficult.

Errors in identifying pins have always been a local problem in the maintenance of electronic equipment. The illustrated connectors in the authored technical data for continuity/resistance/voltage tests were so generic they added little information except perhaps to

remind the user when measurements were to be made between connectors on cables rather than between connectors on the line replaceable units (LRUs). Technical data would have been more useful if blow-ups (enlargements) were made of the connectors with callouts on the pins to be checked. This information to assist in pin identification would be expensive to produce, since it is not presently in the source data, but it may be the only real way to improve performance in this critical subtask.

Effectivity codes are a dynamic characteristic of an A/C, yet these could not be updated easily. Since much of this information is available in CAMS, it would be worthwhile to investigate the possibility of periodically requesting this information from CAMS and updating the state table automatically to reflect these changes.

The authors of the electronic technical data must have an understanding of how the presentation system operates and the rules it uses to process the data. Some data that was legal according to the authoring Style Guide caused problems or did not work as expected. Good communication between the authors and the software developers will ensure that a change in one area has minimum impact on other areas.

Programmatics

The work on this program was performed under two separate contracts with two separate government agencies. As a result, the IMIS program did not have direct control over the authored TO data or the TO Present software. Differing interpretations of requirements for data formats and software between the two separate contractors were difficult to resolve. User interface differences were apparent, transitions between the two systems were noticeable, and the conclusion of the memorandum of agreement resulted in the IMIS contractor having no access to TO Present source code, essentially freezing the as-delivered software with its known problems without any possibility of correction. This could be solved by ensuring that a single agency oversees the development of all software and data associated with the program, and that detailed specifications documenting the interfaces be developed and followed.

Establishment of the Maintenance Review Panel, with its composition of government and contractor personnel with active duty Air Force maintenance experience, was extremely valuable. This group focused on the needs of the ultimate user and allowed a system to be designed and built which kept these needs in the foreground.

There was considerable turnover in personnel over the life of the program, for both the government and the contractors. It is important to maintain continuity of key resources (or at least ensure there is adequate time to communicate previous decisions and agreements) to minimize changes of direction.

Thorough documentation of meetings, conference calls, and action items helps to facilitate effective program management. As documentation improved over the course of the program, our communication, tracking of schedule items, resolution of action items, and overall

program management also improved. Regularly scheduled conference calls were also beneficial, especially in a dynamic environment where face-to-face meetings were impractical.

Maintaining schedule milestones with the necessary level of detail provides visibility into current status, for both the contractor and the government. Early schedules lacked the detail to allow either party to adequately predict schedule impacts, while the more detailed schedules developed later in the program were met with a much higher success rate. It is also important to establish the appropriate cost reporting documentation corresponding to these schedules.

The lack of a contractual requirement for Level 3 hardware drawings resulted in differences between the PMAs built by GDE Systems and the PMAs built by Computer Sciences Corporation (CSC). The hardware documentation provided, which met all contractual requirements, was inadequate to allow a second contractor to build identical PMAs.

Requirement traceability was complicated by the lack of a System Design Document, which would have captured all the requirements implemented for the demonstration system. Some of the IMIS documentation captured the full-up set of requirements, while other documents captured only those requirements which were implemented. If a System Design Document had been developed, proper and meaningful traceability throughout all the documentation could have been established. Any changes to these requirements would need to be promptly reflected in the contract.

A rigorous and well-defined test program must be established to provide the government with confidence that the delivered system will meet the requirements. Acceptance test procedures which are used to verify requirements should not be viewed as procedures to demonstrate all functionality. If the proper test environment is set up and monitored, the acceptance test process can be very effective.

STRATEGIES FOR FURTHER IMPLEMENTATION

As shown by the results described in the second section of this document, the IMIS system evaluated at Luke AFB was successful in demonstrating the IMIS concept and in meeting the objectives identified in the IMIS Operational Concept Document. The next logical step is to apply these concepts across all Air Force weapon system platforms and to make the implementation generic enough so that it can be applied to any maintenance environment (vehicles and communication systems, for example).

The most straightforward example of extending the IMIS concept to another weapon system platform would be for the development of a new weapon system. The requirements for an IMIS system would need to be considered in the specification for the weapon system. This would ensure that the appropriate on-aircraft capabilities and interfaces are developed, and that data is authored to support the weapon system maintenance.

In the case of an existing weapon system platform, a number of factors must be considered. These include the bases at which the weapon system is deployed, the legacy databases with which the system will interact, and the type of interface with the weapon system. It was found that Air Force policies and procedures can be implemented differently from one base to another; consequently, a thorough evaluation of current implementations at these bases is needed to attempt to standardize them to the extent that a single system can be developed and used. Different bases may also utilize different legacy databases (e.g., CAMS vs. Tactical Interim CAMS and Reliability and Maintainability Information System (REMIS) Reporting System (TICARRS)), to suit their unique mission needs.

The extensive hardware requirements to support an Air Force-wide implementation of IMIS will result in additional investigations into the type of hardware required. Sun workstations and customized PMAs may not be the correct answer when considering the acquisition and development costs against the cost of utilizing existing resources and COTS portable devices; for example, a 486-based system would allow utilization of existing hardware at most bases.

While certain aspects of the system are dependent on the weapon system or base, the core of the Maintenance Data Collection (MDC) functionality is standard and independent of these variables. By migrating this MDC functionality to allow more widespread use early in the acquisition process, additional insights can be gained into the resulting efficiency improvements and cost reductions. This could be important, since the activity of quantifying the cost savings of MDC functions as implemented using IMIS has not been performed.

In summary, the Armstrong Laboratory's IMIS program has successfully demonstrated the IMIS concept and has produced a set of specifications which have been used by system implementers for the F-16, F-22, C-17, and B-2. The information gathered from this effort will be a factor in the Integrated Maintenance Data System (IMDS) efforts.

ACRONYMS

A/C	Aircraft
AFB	Air Force Base
AFSC	Air Force Specialty Code
AFTO	Air Force Technical Order
AIP	Aircraft Interface Panel
APG	Airplane General
BIT	Built-In-Test
CAMS	Core Automated Maintenance System
COTS	Commercial Off-the-Shelf
CSC	Computer Sciences Corporation
ETIC	Estimated Time In Commission
FMC	Fully Mission Capable
FRM	Fault Reporting Manual
FS	Fighter Squadron
GUI	Graphical User Interface
IMDS	Integrated Maintenance Data System
IMIS	Integrated Maintenance Information System
IPB	Illustrated Parts Breakdown
JCN	Job Control Number
LRU	Line Replaceable Unit
MDC	Maintenance Data Collection
MESL	Minimum Essential Subsystem List
MIW	Maintenance Information Workstation
MML	Memory Module Loader
MOC	Maintenance Operations Center
NASA	National Aeronautics and Space Administration
NMC	Not Mission Capable
NMCS	Not Mission Capable - Supply
OFP	Operational Flight Program
OIC	Officer in Charge
PMA	Portable Maintenance Aid
PMC	Partially Mission Capable
PWC	Performing Work Center
QRL	Quick Reference List
REMIS	Reliability and Maintainability Information System
RF	Radio Frequency
SBSS	Standard Base Supply System
SCO	Santa Cruz Operation
SQL	Structured Query Language
TICARRS	Tactical Interim CAMS and REMIS Reporting System
TLX	Task Load Index
TO	Technical Order
TO Present	TO Presentation

WCE	Work Center Event
WDC	When Discovered Code
WUC	Work Unit Code

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